# INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990-1998

## DRAFT

# **FEBRUARY 2000**

U.S. Environmental Protection Agency
Office of Policy
401 M St., SW
Washington, D.C. 20460
U.S.A.

[Inside Front Cover]

#### HOW TO OBTAIN COPIES

You may electronically download this document on the U.S. EPA's homepage at <a href="http://www.epa.gov/globalwarming/publications/emissions/">http://www.epa.gov/globalwarming/publications/emissions/</a>. To obtain additional copies of this report, call the National Center for Environmental Publications and Information (NCEPI) at (800) 490-9198.

#### FOR FURTHER INFORMATION

Contact Mr. Wiley Barbour, Environmental Protection Agency, (202) 260-6972, barbour.wiley@epa.gov.

For more information regarding climate change and greenhouse gas emissions see EPA web side at http://www.epa.gov/globalwarming.

Released for printing: [insert date]

[INSERT DISCUSSION OF COVER DESIGN]

# **Acknowledgments**

The Environmental Protection Agency would like to acknowledge the many individual and organizational contributors to this document, without whose efforts this report would not be complete. Although the list of researchers, government employees, and consultants who have provided technical and editorial support is too long to list here, we would like to thank some key contributors whose work has significantly improved this year's report. In particular, we wish to acknowledge the efforts of the Energy Information Administration and the Department of Energy for providing detailed statistics and insightful analysis on numerous energy-related topics; the U.S. Forest Service for preparing the forest carbon inventory, and the Department of Agriculture's Agricultural Research Service for their work on nitrous oxide emissions from soils.

Within the EPA, many Offices contributed data, analysis and technical review for this report. The EPA Office of Atmospheric Programs developed methodologies and provided detailed emission estimates for numerous source categories, particularly for methane, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The Office of Mobile Sources and the Office of Air Quality Planning and Standards provided analysis and review for several of the source categories addressed in this report. The Office of Solid Waste and the Office of Research and Development also contributed analysis and research.

Other government agencies have contributed data as well, including the U.S. Geological Survey, the Federal Highway Administration, the Department of Transportation, the Bureau of Transportation Statistics, the Department of Commerce, and the Federal Aviation Administration.

We would especially like to thank the staff of the Global Environmental Issues Group at ICF Consulting for synthesizing this report and preparing many of the individual analyses.

#### **Preface**

The United States Environmental Protection Agency (EPA) prepares the official *U.S. Inventory of Greenhouse Gas Emissions and Sinks* to comply with existing commitments under the United Nations Framework Convention on Climate Change (UNFCCC)<sup>1</sup>. Under a decision of the UNFCCC Conference of the Parties, national inventories for most UNFCCC Annex I parties should be provided to the UNFCCC Secretariat each year by April 15.

In an effort to engage the public and researchers across the country, the EPA has instituted an annual public review and comment process for this document. The availability of the draft document is announced via Federal Register Notice and is posted on the EPA web page.<sup>2</sup> Copies are also mailed upon request. The public comment period is generally limited to 30 days; however, comments received after the closure of the public comment period are accepted and considered for the next edition of this annual report. The EPA's policy is to allow at least 60 days for public review and comment when proposing new regulations or documents supporting regulatory development – unless statutory or judicial deadlines make a shorter time necessary – and 30 days for non-regulatory documents of an informational nature such as the Inventory document.

### **Table of Contents**

ACKNOWLEDGMENTS	V
PREFACE	V
TABLE OF CONTENTS	V
LIST OF TABLES, FIGURES, AND BOXES	Х
Tables	<b>X</b>
Figures	Х
Boxes	XV
EXECUTIVE SUMMARY	ES-1
Recent Trends in U.S. Greenhouse Gas Emissions	ES-2
Global Warming Potentials	ES-8
Carbon Dioxide Emissions	ES-9
Methane Emissions	ES-13
Nitrous Oxide Emissions	ES-16
HFCs, PFCs and SF <sub>6</sub> Emissions	ES-18
Criteria Pollutant Emissions	ES-20
1. INTRODUCTION	1
What is Climate Change?	2
Greenhouse Gases	2

<sup>&</sup>lt;sup>1</sup> See http://www.unfccc.de

<sup>&</sup>lt;sup>2</sup> See http://www.epa.gov/globalwarming/emissions/national

Global Warming Potentials	6
Recent Trends in U.S. Greenhouse Gas Emissions	8
Methodology and Data Sources	15
Uncertainty in and Limitations of Emission Estimates	15
Organization of Report	16
Changes in This Year's U.S. Greenhouse Gas Inventory Report	17
2. ENERGY	25
Carbon Dioxide Emissions from Fossil Fuel Combustion	26
Stationary Combustion (excluding CO <sub>2</sub> )	39
Mobile Combustion (excluding CO <sub>2</sub> )	43
Coal Mining	47
Natural Gas Systems	50
Petroleum Systems	52
Natural Gas Flaring and Criteria Pollutant Emissions from Oil and Gas Activities	55
International Bunker Fuels	56
Wood Biomass and Ethanol Consumption	61
3. INDUSTRIAL PROCESSES	65
Cement Manufacture	67
Lime Manufacture	70
Limestone and Dolomite Use	72
Soda Ash Manufacture and Consumption	74
Carbon Dioxide Consumption	76
Iron and Steel Production	78
Ammonia Manufacture	79
Ferroalloy Production	81
Petrochemical Production	82
Silicon Carbide Production	84
Adipic Acid Production	85
Nitric Acid Production	86
Substitution of Ozone Depleting Substances	88
Aluminum Production	92
HCFC-22 Production	95
Semiconductor Manufacture	97
Electrical Transmission and Distribution	98
Magnesium Production and Processing	100
Industrial Sources of Criteria Pollutants	102

4.	SOLVENT USE	105
5.	AGRICULTURE	107
Ent	eric Fermentation	108
Ma	nure Management	110
Ric	re Cultivation	113
Agı	ricultural Soil Management	118
Agı	ricultural Residue Burning	125
6.	LAND-USE CHANGE AND FORESTRY	131
Cha	anges in Forest Carbon Stocks	132
Cha	anges in Non-Forest Soil Carbon Stocks	137
Cha	anges in Non-Forest Carbon Stocks in Landfills	140
7.	WASTE	143
Lar	ndfills	144
Wa	ste Combustion	147
Wa	stewater Treatment	150
Huı	man Sewage	151
Wa	ste Sources of Criteria Pollutants	153
RE	FERENCES	155
Exe	ecutive Summary	155
Intr	roduction	155
Ene	ergy	159
Ind	ustrial Processes	165
Sol	vent Use	172
Agı	riculture	172
Lar	nd-Use Change and Forestry	182
Wa	iste	184
A١	INEXES	187
Lis	t of Annexes	187
AN	NEX A: Methodology for Estimating Emissions of CO <sub>2</sub> from Fossil Fuel Combustion	189
	NEX B: Methodology for Estimating Emissions of CH <sub>4</sub> , N <sub>2</sub> O, and Criteria Pollutants from Stationary mbustion	203
AN	NEX C: Methodology for Estimating Emissions of CH <sub>4</sub> , N <sub>2</sub> O, and Criteria Pollutants from Mobile Co	mbustion 207
AN	NEX D: Methodology for Estimating Methane Emissions from Coal Mining	217
AN	NEX E: Methodology for Estimating Methane Emissions from Natural Gas Systems	223
ΑN	NEX F: Methodology for Estimating Methane Emissions from Petroleum Systems	227

ANNEX G: Methodology for Estimating Emissions from International Bunker Fuels used by the U.S. Military	233
ANNEX H: Methodology for Estimating Methane Emissions from Enteric Fermentation	237
ANNEX I: Methodology for Estimating Methane Emissions from Manure Management	241
ANNEX J: Methodology for Estimating Methane Emissions from Landfills	247
ANNEX K: Global Warming Potential Values	251
ANNEX L: Ozone Depleting Substance Emissions	253
ANNEX M: Sulfur Dioxide Emissions	257
ANNEX N: Complete List of Sources	259
ANNEX O: IPCC Reference Approach for Estimating CO <sub>2</sub> Emissions from Fossil Fuel Combustion	261
ANNEX P: Sources of Greenhouse Gas Emissions Excluded	271
ANNEX Q: Constants, Units, and Conversions	277
ANNEX R: Abbreviations	281
ANNEX S: Chemical Symbols	283
ANNEX T: Glossary	285

# List of Tables, Figures, and Boxes

# Tables

Table ES-1: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (MMTCE)	ES-2
Table ES-2: Annual Change in CO <sub>2</sub> Emissions from Fossil Fuel Combustion for Selected Fuels and Sectors (MMTCE and Percent)	ES-4
Table ES-3: Recent Trends in Various U.S. Data (Index 1990 = 100)	ES-5
Table ES-4: Transportation-Related Greenhouse Gas Emissions (MMTCE)	ES-6
Table ES-5: Electric Utility-Related Greenhouse Gas Emissions (MMTCE)	ES-8
Table ES-6: Global Warming Potentials (100 Year Time Horizon)	ES-8
Table ES-7: U.S. Sources of CO <sub>2</sub> Emissions and Sinks (MMTCE)	ES-9
Table ES-8: CO <sub>2</sub> Emissions from Fossil Fuel Combustion by End-Use Sector (MMTCE)	ES-11
Table ES-9: U.S. Sources of Methane Emissions (MMTCE)	ES-14
Table ES-10: U.S. Sources of Nitrous Oxide Emissions (MMTCE)	ES-16
Table ES-11: Emissions of HFCs, PFCs, and SF <sub>6</sub> (MMTCE)	ES-18
Table ES-12: Emissions of Ozone Depleting Substances (Gg)	ES-20
Table ES-13: Emissions of NO <sub>x</sub> , CO, NMVOCs, and SO <sub>2</sub> (Gg)	ES-21
Table 1-1: Global Warming Potentials and Atmospheric Lifetimes (Years)	7
Table 1-2: Annual Change in CO <sub>2</sub> Emissions from Fossil Fuel Combustion for Selected Fuels and Sectors (Mand Percent)	MTCE 8
Table 1-3: Recent Trends in Various U.S. Data (Index 1990 = 100)	10
Table 1-4: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (MMTCE)	10
Table 1-5: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Gg)	11
Table 1-6: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (MMTCE)	12
Table 1-7: Transportation-Related Greenhouse Gas Emissions (MMTCE)	13
Table 1-8: Electric Utility-Related Greenhouse Gas Emissions (MMTCE)	14
Table 1-9: IPCC Sector Descriptions	16
Table 1-10: List of Annexes	17
Table 2-1: Emissions from Energy (MMTCE)	25
Table 2-2: Emissions from Energy (Tg)	26
Table 2-3: CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Fuel Type and Sector (MMTCE)	27
Table 2-4: CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Fuel Type and Sector (Tg)	28
Table 2-5: Fossil Fuel Carbon in Products and CO <sub>2</sub> Emissions from International Bunker Fuel Combustion (MMTCE)	29
Table 2-6: Fossil Fuel Carbon in Products and CO <sub>2</sub> Emissions from International Bunker Fuel Combustion (T	Tg CO <sub>2</sub> ) 29
Table 2-7: CO <sub>2</sub> Emissions from Fossil Fuel Combustion by End-Use Sector (MMTCE)	30

Table 2-8: CO <sub>2</sub> Emissions from Fossil Fuel Combustion in Transportation End-Use Sector (MMTCE)	32
Table 2-9: Carbon Intensity from Direct Fossil Fuel Combustion by Sector (MMTCE/EJ)	35
Table 2-10: Carbon Intensity from Energy Consumption by Sector (MMTCE/EJ)	36
Table 2-11: Change in CO <sub>2</sub> Emissions from Direct Fossil Fuel Combustion Since 1990 (MMTCE)	36
Table 2-12: CH <sub>4</sub> Emissions from Stationary Combustion (MMTCE)	40
Table 2-13: N <sub>2</sub> O Emissions from Stationary Combustion (MMTCE)	40
Table 2-14: CH <sub>4</sub> Emissions from Stationary Combustion (Gg)	41
Table 2-15: N <sub>2</sub> O Emissions from Stationary Combustion (Gg)	41
Table 2-16: CH <sub>4</sub> Emissions from Mobile Combustion (MMTCE)	43
Table 2-17: N <sub>2</sub> O Emissions from Mobile Combustion (MMTCE)	44
Table 2-18: CH <sub>4</sub> Emissions from Mobile Combustion (Gg)	44
Table 2-19: N <sub>2</sub> O Emissions from Mobile Combustion (Gg)	45
Table 2-20: CH <sub>4</sub> Emissions from Coal Mining (MMTCE)	48
Table 2-21: CH <sub>4</sub> Emissions from Coal Mining (Gg)	48
Table 2-22: Coal Production (Thousand Metric Tons)	50
Table 2-23: CH <sub>4</sub> Emissions from Natural Gas Systems (MMTCE)	51
Table 2-24: CH <sub>4</sub> Emissions from Natural Gas Systems (Gg)	51
Table 2-25: CH <sub>4</sub> Emissions from Petroleum Systems (MMTCE)	53
Table 2-26: CH <sub>4</sub> Emissions from Petroleum Systems (Gg)	53
Table 2-27: Uncertainty in CH <sub>4</sub> Emissions from Production Field Operations (Gg)	55
Table 2-28: CO <sub>2</sub> Emissions from Natural Gas Flaring	55
Table 2-29: NO <sub>x</sub> , NMVOCs, and CO Emissions from Oil and Gas Activities (Gg)	55
Table 2-30: Total Natural Gas Reported Vented and Flared (Million Ft <sup>3</sup> ) and Thermal Conversion Factor (Btu/Ft	t <sup>3</sup> ) 56
Table 2-31: Emissions from International Bunker Fuels (MMTCE)	58
Table 2-32: Emissions from International Bunker Fuels (Gg)	58
Table 2-33: Aviation Jet Fuel Consumption for International Transport (Million Gallons)	60
Table 2-34: Marine Fuel Consumption for International Transport (Million Gallons)	60
Table 2-35: CO <sub>2</sub> Emissions from Wood Consumption by End-Use Sector (MMTCE)	61
Table 2-36: CO <sub>2</sub> Emissions from Wood Consumption by End-Use Sector (Gg)	61
Table 2-37: CO <sub>2</sub> Emissions from Ethanol Consumption	62
Table 2-38: Woody Biomass Consumption by Sector (Trillion Btu)	62
Table 2-39: Ethanol Consumption	63
Table 3-1: Emissions from Industrial Processes (MMTCE)	66
Table 3-2: Emissions from Industrial Processes (Gg)	67
Table 3-3: CO <sub>2</sub> Emissions from Cement Production	68
Table 3-4: Cement Production (Thousand Metric Tons)	69

Table 3-5: Net CO <sub>2</sub> Emissions from Lime Manufacture	70
Table 3-6: CO <sub>2</sub> Emissions from Lime Manufacture (Gg)	70
Table 3-7: Lime Production and Lime Use for Sugar Refining and PCC (Thousand Metric Tons)	7
Table 3-8: CO <sub>2</sub> Emissions from Limestone & Dolomite Use (MMTCE)	72
Table 3-9: CO <sub>2</sub> Emissions from Limestone & Dolomite Use (Gg)	73
Table 3-10: Limestone & Dolomite Consumption (Thousand Metric Tons)	74
Table 3-11: CO <sub>2</sub> Emissions from Soda Ash Manufacture and Consumption	75
Table 3-12: CO <sub>2</sub> Emissions from Soda Ash Manufacture and Consumption (Gg)	75
Table 3-13: Soda Ash Manufacture and Consumption (Thousand Metric Tons)	76
Table 3-14: CO <sub>2</sub> Emissions from Carbon Dioxide Consumption	77
Table 3-15: Carbon Dioxide Consumption	77
Table 3-16: CO <sub>2</sub> Emissions from Iron and Steel Production	78
Table 3-17: Pig Iron Production	79
Table 3-18: CO <sub>2</sub> Emissions from Ammonia Manufacture	80
Table 3-19: Ammonia Manufacture	80
Table 3-20: CO <sub>2</sub> Emissions from Ferroalloy Production	81
Table 3-21: Production of Ferroalloys (Metric Tons)	82
Table 3-22: CH <sub>4</sub> Emissions from Petrochemical Production	83
Table 3-23: Production of Selected Petrochemicals (Thousand Metric Tons)	83
Table 3-24: CH <sub>4</sub> Emissions from Silicon Carbide Production	84
Table 3-25: Production of Silicon Carbide	84
Table 3-26: N <sub>2</sub> O Emissions from Adipic Acid Production	85
Table 3-27: Adipic Acid Production	86
Table 3-28: N <sub>2</sub> O Emissions from Nitric Acid Production	87
Table 3-29: Nitric Acid Production	87
Table 3-30: Emissions of HFCs and PFCs from ODS Substitution (MMTCE)	88
Table 3-31: Emissions of HFCs and PFCs from ODS Substitution (Mg)	88
Table 3-32: CO <sub>2</sub> Emissions from Aluminum Production	93
Table 3-33: PFC Emissions from Aluminum Production (MMTCE)	93
Table 3-34: PFC Emissions from Aluminum Production (Gg)	93
Table 3-35: Production of Primary Aluminum	9:
Table 3-36: HFC-23 Emissions from HCFC-22 Production	90
Table 3-37: Emissions of Fluorinated Greenhouse Gases from Semiconductor Manufacture	9′
Table 3-38: SF <sub>6</sub> Emissions from Electrical Transmission and Distribution	99
Table 3-39: SF <sub>6</sub> Emissions from Magnesium Production and Processing	100
Table 3-40: 1998 Potential and Actual Emissions of HFCs, PFCs, and SF <sub>6</sub> from Selected Sources (MMTCE)	10

Table 3-41: NO <sub>x</sub> , CO, and NMVOC Emissions from Industrial Processes (Gg)	102
Table 4-1: Emissions of NO <sub>x</sub> , CO, and NMVOC from Solvent Use (Gg)	105
Table 5-1: Emissions from Agriculture (MMTCE)	107
Table 5-2: Emissions from Agriculture (Gg)	107
Table 5-3: CH <sub>4</sub> Emissions from Enteric Fermentation (MMTCE)	108
Table 5-4: CH <sub>4</sub> Emissions from Enteric Fermentation (Gg)	108
Table 5-5: Cow Populations (Thousands) and Milk Production (Million Kilograms)	110
Table 5-6: CH <sub>4</sub> and N <sub>2</sub> O Emissions from Manure Management (MMTCE)	11
Table 5-7: CH <sub>4</sub> Emissions from Manure Management (Gg)	112
Table 5-8: N <sub>2</sub> O Emissions from Manure Management (Gg)	112
Table 5-9: CH <sub>4</sub> Emissions from Rice Cultivation (MMTCE)	114
Table 5-10: CH <sub>4</sub> Emissions from Rice Cultivation (Gg)	115
Table 5-11: Rice Areas Harvested (Hectares)	110
Table 5-12: Rice Flooding Season Lengths (Days)	117
Table 5-13: N <sub>2</sub> O Emissions from Agricultural Soil Management (MMTCE)	118
Table 5-14: N <sub>2</sub> O Emissions from Agricultural Soil Management (Gg)	118
Table 5-15: Commercial Fertilizer Consumption & Land Application of Sewage Sludge (Thousand Meta Nitrogen)	ric Tons of
Table 5-16: Animal Excretion from Livestock and Poultry (Thousand Metric Tons of Nitrogen)	123
Table 5-17: Nitrogen Fixing Crop Production (Thousand Metric Tons of Product)	123
Table 5-18: Corn and Wheat Production (Thousand Metric Tons of Product)	123
Table 5-19: Histosol Area Cultivated (Thousand Hectares)	123
Table 5-20: Direct N <sub>2</sub> O Emissions from Agricultural Cropping Practices (MMTCE)	123
Table 5-21: Direct N <sub>2</sub> O Emissions from Pasture, Range, and Paddock Animals (MMTCE)	124
Table 5-22: Indirect N <sub>2</sub> O Emissions (MMTCE)	124
Table 5-23: Emissions from Agricultural Residue Burning (MMTCE)	125
Table 5-24: Emissions from Agricultural Residue Burning (Gg)	125
Table 5-25: Agricultural Crop Production (Thousand Metric Tons of Product)	127
Table 5-26: Percentage of Rice Area Burned By State	128
Table 5-27: Percentage of Rice Area Burned	128
Table 5-28: Key Assumptions for Estimating Emissions from Agricultural Residue Burning	128
Table 5-29: Greenhouse Gas Emission Ratios	128
Table 6-1: Net CO <sub>2</sub> Flux from Land-Use Change and Forestry (MMTCE)	13
Table 6-2: Net CO <sub>2</sub> Flux from Land-Use Change and Forestry (Gg)	132
Table 6-3: Net CO <sub>2</sub> Flux from U.S. Forests (MMTCE)	134
Table 6-4: Net CO <sub>2</sub> Flux from U.S. Forests (Gg)	134
Table 6-5: U.S. Forest Carbon Stock Estimates (Gg)	136

Table 6-6: Net CO <sub>2</sub> Flux From Non-Forest Soils (MMTCE)	138
Table 6-7: Net CO <sub>2</sub> Flux From Non-Forest Soils (Gg)	138
Table 6-8: Quantities of Applied Minerals (Thousand Metric Tons)	140
Table 6-9: Net CO <sub>2</sub> Flux from Non-Forest Carbon Stocks in Landfills	140
Table 6-10: Composition of Yard Trimmings (%) in MSW and Carbon Storage Factor (Gg Carbon/Gg Yard Trimmings)	141
Table 6-11: Yard Trimmings Disposal to Landfills	141
Table 7-1: Emissions from Waste (MMTCE)	143
Table 7-2: Emissions from Waste (Gg)	143
Table 7-3: CH <sub>4</sub> Emissions from Landfills (MMTCE)	146
Table 7-4: CH <sub>4</sub> Emissions from Landfills (Gg)	146
Table 7-5: CO <sub>2</sub> and N <sub>2</sub> O Emissions from Waste Combustion (MMTCE)	147
Table 7-6: CO <sub>2</sub> and N <sub>2</sub> O Emissions from Waste Combustion (Gg)	147
Table 7-7: 1997 Plastics in the Municipal Solid Waste Stream by Resin (Thousand Metric Tons)	148
Table 7-8: 1997 Factors for Calculating CO <sub>2</sub> Emissions from Combusted Plastics	148
Table 7-9: Municipal Solid Waste Generation (Metric Tons) and Percent Combusted	149
Table 7-10: U.S. Municipal Solid Waste Combusted by Data Source (Metric Tons)	149
Table 7-11: CH <sub>4</sub> Emissions from Domestic Wastewater Treatment	150
Table 7-12: U.S. Population (Millions) and Wastewater BOD Produced (Gg)	151
Table 7-13: N <sub>2</sub> O Emissions from Human Sewage	152
Table 7-14: U.S. Population (Millions) and Average Protein Intake (kg/Person/Year)	152
Table 7-15: Emissions of NO <sub>x</sub> , CO, and NMVOC from Waste (Gg)	153
Table A-1: 1998 Energy Consumption Data and CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Fuel Type	192
Table A-2: 1997 Energy Consumption Data and CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Fuel Type	193
Table A-3: 1996 Energy Consumption Data and CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Fuel Type	194
Table A-4: 1995 Energy Consumption Data and CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Fuel Type	195
Table A-5: 1994 Energy Consumption Data and CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Fuel Type	196
Table A-6: 1993 Energy Consumption Data and CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Fuel Type	197
Table A-7: 1992 Energy Consumption Data and CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Fuel Type	198
Table A-8: 1991 Energy Consumption Data and CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Fuel Type	199
Table A-9: 1990 Energy Consumption Data and CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Fuel Type	200
Table A-10: 1998 Emissions From International Bunker Fuel Consumption	201
Table A-11: 1998 Carbon In Non-Energy Products	201
Table A-12: Key Assumptions for Estimating Carbon Dioxide Emissions	201
Table A-13: Annually Variable Carbon Content Coefficients by Year (MMTCE/QBtu)	202
Table A-14: Electricity Consumption by End-Use Sector (Billion Kilowatt-Hours)	202
Table B-1: Fuel Consumption by Stationary Combustion for Calculating CH <sub>4</sub> and N <sub>2</sub> O Emissions (TBtu)	204

Table B-2: CH <sub>4</sub> and N <sub>2</sub> O Emission Factors by Fuel Type and Sector (g/GJ)	204
Table B-3: NO <sub>x</sub> Emissions from Stationary Combustion (Gg)	205
Table B-4: CO Emissions from Stationary Combustion (Gg)	205
Table B-5: NMVOC Emissions from Stationary Combustion (Gg)	206
Table C-1: Vehicle Miles Traveled for Gasoline Highway Vehicles (10 <sup>9</sup> Miles)	209
Table C-2: Vehicle Miles Traveled for Diesel Highway Vehicles (10 <sup>9</sup> Miles)	209
Table C-3: VMT Profile by Vehicle Age (Years) and Vehicle/Fuel Type for Highway Vehicles (Percent of VM	T) 210
Table C-4: Fuel Consumption for Non-Highway Vehicles by Fuel Type (U.S. Gallons)	210
Table C-5: Control Technology Assignments for Gasoline Passenger Cars (Percent of VMT)	211
Table C-6: Control Technology Assignments for Gasoline Light-Duty Trucks (Percent of VMT)	212
Table C-7: Control Technology Assignments for California Gasoline Passenger Cars and Light-Duty Trucks (Percent of VMT)	212
Table C-8: Control Technology Assignments for Gasoline Heavy-Duty Vehicles (Percent of VMT)	212
Table C-9: Control Technology Assignments for Diesel Highway VMT	212
Table C-10: Emission Factors (g/km) for CH <sub>4</sub> and N <sub>2</sub> O and "Fuel Economy" (g CO <sub>2</sub> /km) for Highway Mobile Combustion	213
$Table \ C-11: \ Emission \ Factors \ for \ CH_4 \ and \ N_2O \ Emissions \ from \ Non-Highway \ Mobile \ Combustion \ (g/kg \ Fuel)$	213
Table C-12: NO <sub>x</sub> Emissions from Mobile Combustion, 1990-1998 (Gg)	214
Table C-13: CO Emissions from Mobile Combustion, 1990-1998 (Gg)	214
Table C-14: NMVOCs Emissions from Mobile Combustion, 1990-1998 (Gg)	215
Table D-1: Mine-Specific Data Used to Estimate Ventilation Emissions	217
Table D-2: Coal Basin Definitions by Basin and by State	219
Table D-3: Annual Coal Production (Thousand Short Tons)	220
Table D-4: Coal Surface and Post-Mining Methane Emission Factors (ft <sup>3</sup> Per Short Ton)	220
Table D-5: Underground Coal Mining Methane Emissions (Billion Cubic Feet)	22
Table D-6: Total Coal Mining Methane Emissions (Billion Cubic Feet)	22
Table D-7: Total Coal Mining Methane Emissions by State (Million Cubic Feet)	22
Table E-1: 1992 Data and Emissions (Mg) for Venting and Flaring from Natural Gas Field Production Stage	224
Table E-2: Activity Factors for Key Drivers	225
Table E-3: CH <sub>4</sub> Emission Estimates for Venting and Flaring from the Field Production Stage (Mg)	226
Table F-1: CH <sub>4</sub> Emissions from Petroleum Production Field Operations	228
Table F-2: 1998 CH <sub>4</sub> Emissions from Petroleum Transportation	229
Table F-3: CH <sub>4</sub> Emissions from Petroleum Refining	230
Table F-4: Summary of CH <sub>4</sub> Emissions from Petroleum Systems (Gg)	230
Table G-1: Transportation Fuels (Gallons) from Domestic Fuel Deliveries	235
Table G-2: Total U.S. DoD Aviation Bunker Fuel (Million Gallons)	236

Table G-3: Total U.S. DoD Maritime Bunker Fuel (Million Gallons)	236
Table H-1: Livestock Population (Thousand Head)	238
Table H-2: Dairy Cow CH <sub>4</sub> Emission Factors and Milk Production Per Cow	238
Table H-3: CH <sub>4</sub> Emission Factors Beef Cows and Replacements (kg/Head/Year)	238
Table H-4: Methane Emissions from Livestock Enteric Fermentation (Gg)	238
Table H-5: Enteric Fermentation CH <sub>4</sub> Emission Factors	239
Table I-1: Livestock Population (1,000 Head)	242
Table I-2: Dairy Cow Weighted MCF Values	243
Table I-3: Swine Weighted MCF Values	244
Table I-4: Dairy Cow and Swine Constants	245
Table I-5: CH <sub>4</sub> Emissions from Livestock Manure Management (Gg)	245
Table J-1: Municipal Solid Waste (MSW) Contributing to Methane Emissions (Tg)	248
Table J-2: Methane Emissions from Landfills (Gg)	248
Table J-3: Municipal Solid Waste Landfill Size Definitions (Gg)	248
Table K-1: Global Warming Potentials and Atmospheric Lifetimes (Years)	251
Table L-1: Emissions of Ozone Depleting Substances (Gg)	253
Table M-1: SO <sub>2</sub> Emissions (Gg)	257
Table M-2: SO <sub>2</sub> Emissions from Electric Utilities (Gg)	258
Table O-1: 1998 U.S. Energy Statistics (Physical Units)	265
Table O-2: Conversion Factors to Energy Units (Heat Equivalents)	265
Table O-3: 1998 Apparent Consumption of Fossil Fuels (TBtu)	266
Table O-4: 1998 Potential Carbon Emissions	267
Table O-5: 1998 Non-Energy Carbon Stored in Products	269
Table O-6: Reference Approach CO <sub>2</sub> Emissions from Fossil Fuel Consumption (MMTCE unless otherwise	e noted) 269
Table O-7: 1998 Energy Consumption in the United States: Sectoral vs. Reference Approaches (TBtu)	269
Table O-8: 1998 CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Estimating Approach (MMTCE)	269
Table Q-1: Guide to Metric Unit Prefixes	277
Table Q-2: Conversion Factors to Energy Units (Heat Equivalents)	279
Table S-1: Guide to Chemical Symbols	283
Figures	
Figure ES-1: U.S. GHG Emissions by Gas	ES-2
Figure ES-2: Annual Percent Change in U.S. GHG Emissions	ES-2
Figure ES-3: Absolute Change in U.S. GHG Emissions Since 1990	ES-2
Figure ES-4: 1998 Greenhouse Gas Emissions by Gas	ES-3
Figure ES-5: U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product	ES-6

Figure ES-6: 1998 Sources of CO <sub>2</sub>	ES-9
Figure ES-7: 1998 U.S. Energy Consumption by Energy Source	ES-10
Figure ES-8: U.S. Energy Consumption (Quadrillion Btu)	ES-10
Figure ES-9: 1998 CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Sector and Fuel Type	ES-11
Figure ES-10: 1998 End-Use Sector Emissions of CO <sub>2</sub> from Fossil Fuel Combustion	ES-11
Figure ES-11: 1998 Sources of CH <sub>4</sub>	ES-14
Figure ES-12: 1998 Sources of N <sub>2</sub> O	ES-16
Figure ES-13: 1998 Sources of HFCs, PFCs, and SF <sub>6</sub>	ES-18
Figure 1-1: U.S. GHG Emissions by Gas	8
Figure 1-2: Annual Percent Change in U.S. GHG Emissions	8
Figure 1-3: Absolute Change in U.S. GHG Emissions Since 1990	8
Figure 1-4: U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product	10
Figure 1-5: U.S. GHG Emissions by Chapter/IPCC Sector	12
Figure 2-1: 1998 Energy Chapter GHG Sources	25
Figure 2-2: 1998 U.S. Energy Consumption by Energy Source	26
Figure 2-3: U.S. Energy Consumption (Quadrillion Btu)	26
Figure 2-4: 1998 CO <sub>2</sub> Emissions from Fossil Fuel Combustion by Sector and Fuel Type	27
Figure 2-5: Fossil Fuel Production Prices	27
Figure 2-6: 1998 End-Use Sector Emissions of CO <sub>2</sub> from Fossil Fuel Combustion	30
Figure 2-7: Motor Gasoline Retail Prices (Real)	31
Figure 2-8: Motor Vehicle Fuel Efficiency	31
Figure 2-9: Heating Degree Days	33
Figure 2-10: Cooling Degree Days	33
Figure 2-11: Electric Utility Retail Sales by End-Use Sector	33
Figure 2-12: Change in CO <sub>2</sub> Emissions from Fossil Fuel Combustion Since 1990 by End-Use Sector	36
Figure 2-13: Mobile Source CH <sub>4</sub> and N <sub>2</sub> O Emissions	43
Figure 3-1: 1998 Industrial Processes Chapter GHG Sources	65
Figure 5-1: 1998 Agriculture Chapter GHG Sources	107
Figure 5-2: Sources of N <sub>2</sub> O Emissions from Agricultural Soils	118
Figure 7-1: 1998 Waste Chapter GHG Sources	143
Boxes	
Box ES-1: Recent Trends in Various U.S. Greenhouse Gas Emissions-Related Data	ES-5
Box ES-2: Greenhouse Gas Emissions from Transportation Activities	ES-6
Box ES-3: Greenhouse Gas Emissions from Electric Utilities	ES-7
Box ES-4: Emissions of Ozone Depleting Substances	ES-19
Box ES-5: Sources and Effects of Sulfur Dioxide	ES-22

Box 1-1: Recent Trends in Various U.S. Greenhouse Gas Emissions-Related Data	9
Box 1-2: Greenhouse Gas Emissions from Transportation Activities	13
Box 1-3: Greenhouse Gas Emissions from Electric Utilities	14
Box 2-1: Sectoral Carbon Intensity Trends Related to Fossil Fuel and Overall Energy Consumption	34
Box 3-1: Potential Emission Estimates of HFCs, PFCs, and SF <sub>6</sub>	101
Box 7-1: Biogenic Emissions and Sinks of Carbon	144
Box 7-2: Recycling and Greenhouse Gas Emissions and Sinks	145